ardized pyrheliometers. Observations have been made at Washington (sea level); Bassour, Algeria (1,160 meters); Mount Wilson, Cal. (1,730 meters): and Mount Whitney, Cal. (4,420 meters). They have continued during all the years 1903 to 1914. Great changes from day to day and from place to place in temperature, in barometric pressure, in humidity, in haziness, while of course greatly affecting measurements of intensity at the stations and of atmospheric transparency computed, nevertheless have not produced differences of the solar constant values. This seems to us to be strong evidence of the soundness of the method.

In the second place, it has been shown by Fowle that the atmospheric transmission coefficients obtained at Mount Wilson fit well with Lord Rayleigh's theory of atmospheric scattering, except for those regions of spectrum where numerous atmospheric lines and bands of true absorption are known to occur. Fowle has computed from the transmission coefficients that the number of molecules per cubic centimeter of air at standard temperature and pressure is $(2.70 \pm 0.02) \times 10^{19}$. This value is very close to Millikan's determination by absolutely independent observations and methods, namely $(2.705 \pm 0.005) \times 10^{19}$.

In the third place, simultaneous solar-constant observations at Mount Wilson and Bassour, separated by one-third the earth's circumference, unite in showing a substantial irregular variability of the sun from day to day. This solar variability has been of late independently confirmed by us by examination of the distribution of brightness along the diameter of the sun's disk. The latter observations show variations of distribution from day to day, and these accompany pretty closely the variations of the total solar radiation. It seems to us that, as the fact of solar variability is thus independently confirmed as a real phenomenon, it speaks favorably for the substantial accuracy of our solar-constant measurements that it was through them that the irregular variations of from 1 to 5 or, very rarely, 10 per cent were first discovered.

Notwithstanding these evidences of the soundness of our solar constant work, various attacks upon it have been made, tending to show that the solar constant is much higher than 1.93 calories, perhaps even 3.5 to 4.0 calories. A principal argument is that the atmospheric transparency continually diminishes as the sun rises within 75° zenith distance, so that our values of atmospheric transmission are much too great and have no relation to the transmission of an atmosphere of constant transparency. Secondly, it is said that measurements of solar radiation exceeding 1.93 calories have been made on mountain tops and from free balloons. Various other objections are raised, which we discuss in our paper now being published by the Smithsonian Institution.[2]

On two days, September 20 and 21, 1914, we continued solar-constant observations at Mount Wilson from the instant of sunrise until about 10 o'clock. We have reduced the work by the aid of Bemporad's air-mass formulæ and tables. As these postulated uniform optical quality of the atmosphere from bottom to top, it was necessary to apply certain corrections to them varying with the wave-length, depending upon the extinction by water vapor residing in the lowest atmospheric strata. We were enabled to determine these corrections by Fowle's studies of the effects of water vapor. We find on both days that the atmospheric transparency remained sensibly unaltered from sunrise to 10 o'clock. Closely iden-

tical values of the solar constant are obtained, whatever the range of air masses used to determine the atmospheric transmission. We made three independent estimates for each day, for air-mass ranges 1.3 to 4; 4 to 12; and 1.3 to 20, respectively. All six solar-constant values thus found fall between 1.90 and 1.95 calories. The smallest air masses, as it happens, yield slightly the highest values. We conclude that our previous results have not been made too small by neglecting to observe during the time when the sun is within 15° of the horizon.

On July 11, 1914, in cooperation with the United States Weather Bureau, a recording pyrheliometer attached to sounding balloons was sent up to the altitude of about 24 km., where the barometric pressure was 3 cm. of mercury, which is only one twenty-fifth of that prevailing at sea level.

Good records of solar radiation were obtained over a period of more than an hour and including the period when the instrument reached its highest elevation. The mean value of the best three records made at highest altitudes, as reduced to mean solar distance, comes out 1.84 calories per square centimeter per minute. We believe that about 2 per cent should be added to represent radiation scattered and absorbed in the atmosphere above the level reached, making the probable value of the solar constant, from this day's work, 1.88 calories. This value falls decidedly within the range of solar constant values we have observed. We state in connection with it the following results, which are the highest reliable direct observations of solar radiation at the various altitudes, as reduced to mean solar distance and vertical sun:

TABLE 1.—*The highest reliable direct observations of solar radiation at the various altitudes.*

[Reduced to mean solar distance and vertical sun.]

Station.	Washington.	Mount Wilson.	Mount Whitney.	Manned balloon.	Free balloon.
Altitude......	127 m........	1,730 m....	4,420 m......	7,500 m......	24,000 m.
Barometer....	75 cm.......	62 cm.......	45 cm.......	30 cm........	3 cm.
Radiation....	1.58 cal......	1.64.........	1.72........	1.755........	1.84 cal.
Observer......	Kimball....	Abbot.......	Abbot.......	A. Peppler..	(Smithsonian.)

SOLAR HALO OF MAY 11, 1915, AT SAND KEY, FLA.
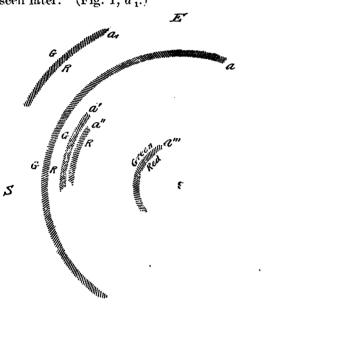
By CLARENCE G. ANDRUS, Assistant Observer.

[Dated: Weather Bureau, Sand Key, Fla., May 11, 1915.]

On the afternoon of May 11, 1915, there was observed at Sand Key, Fla. ($\varphi = 24°\ 27'$ N.; $\lambda = 81°\ 53'$ W.), a rather unusual display of prismatic arcs in the heavens. The phenomena were observed and noted with the strictest accuracy possible under the circumstances, but it is regretted that no instrumental measurements and no photographs of the halos could be secured. The somewhat crude observing methods practicable were carefully carried out and the author feels certain that errors were nearly eliminated. All records are in 90th meridian time. The observations were made by the writer, and Mr. H. L. Riley carefully checked and confirmed the data.

The cloud forms causing the phenomena were of the cirro-stratus type and were moving toward the east. Throughout the afternoon the sky was about 5/10 covered, the cirro-stratus being arranged as a broad band from east to west. The edge to the southward was well defined and appeared as an upwardly curling front on which no halo-form curves were seen. In structure the clouds were not of pallium form but were filamentary and might well be described as resembling the warp and woof threads in a threadbare cloth.

² Abbott, C. G., *and others. New evidence on the intensity of solar radiation outside the atmosphere.* Washington, 1915. p. 1., 55 p. 8°. (Smithsonian misc. coll., v. 65, no. 4. Publ. 2301.)

The first suggestion of a halo was manifest at 2:20 p. m. when a short arc of 22° radius appeared between the zenith and the sun. Five minutes later, while viewing the developing halo, I became faintly aware of other curves within the ordinary halo. All doubts were removed at 2:35 p. m., when the inner curves assumed faint but definite colors and the arcs increased in length. I immediately measured them and sketched an outline of the general features. This sketch corresponded with the sketch made later (at 3:00 p. m.; see fig. 1), except that the curve at 28°–29° was not yet visible. As a check, the ordinary halo was measured; the result was 22° 50', a trifle too large. The radii of the inner ones were not established at this time. During the next 15 minutes the distinctness of the whole phenomenon fluctuated to a considerable extent and at times portions became nearly lost to the eye. At this time glimpses were had of a colored curve lying outside of the 22° arc. This curve was clearly seen later. (Fig. 1, a_1.)

a, halo of 22°; *a₁*, halo of 28°–29°; *a′*, halo of 18°–19°; *a″*, halo of 17°–18°; *a‴*, halo of 8°–9°

FIG. 1.—Sketch of halos of abnormal radius observed at Sand Key, Fla., on May 11, 1915, at 3:00 p. m., 90th merid. time, by C. G. Andrus, Assistant Observer, Weather Bureau. The brightness varied inversely as the depth of the shading.

Conditions became exceptionally favorable at 3 p. m. The entire spectacle was then at its best. Then it was that the five concentric curves were clearly visible simultaneously. The unusual radius was more striking in each case than was the brightness or attractiveness of the display. The 8°–9° arc could not be definitely seen beside the unshaded sun, and but for the fact that its red color was on its inner circumference, it might have been mistaken for a corona of large radius. A sketch, drawn from the rough original, of the aspect of the phenomena at 3:00 p. m. is reproduced in figure 1. This sketch, however, fails to indicate that the two arcs of about 18° radius do not merge but are separated by a space of about ½ degree in width.

The angular measurements of the radii of the halos were made with the aid of three pins, A, B, and C, stuck in a pad of paper. Pins A and C were thrust in permanently and in such a way that when A is nearer the sun the pin's shadow is quite long and always falls upon C or on the line connecting C and A. While keeping A thus accurately pointed toward the sun, the observer having his eye at C, the third pin, B, is inserted so that it is in line with the halo to be measured and with the eye at C. Thus is obtained a graphic representation of the angle ACB (sun–eye–halo) which is resolved by the use of right triangles and the trigonometric ratios. This method was used for the measurement of all but the innermost and outermost arcs. The innermost one was too near the dazzling sun and the outermost was fast fading when its measure was about to be taken. This latter one was estimated to have a radius about one and one-third times that of the 22° halo.

At 3:09 p. m. all arcs but the 22°-halo had faded; but a careful watch was kept and at 4:25 p. m. a sun-dog began to brighten to the left of the sun and at his altitude, on the outer edge of the 22° halo. At 4:30 p. m. the arc of the circumzenithal circle was observed and measurements and a sketch were at once made (4:33 p. m.). The sun's altitude was gaged to be slightly less than 18° and the solar distance to the nearest portion of the circumzenithal arc as slightly less than 45°. At 4:52 p. m. the distance of the arc from the sun was measured as 53°. There is a possibility that this is slightly too large, but the error should not be more than 1¼°. The arc had faded at 5:00 p. m., but the parhelion remained until 5:05 p. m., and the halo continued visible until shortly before sunset.

In regard to the arrangement of the colors of the arcs, it was especially noted that in the case of all five halo-curves, the parhelion, and the circumzenithal arc, the red of the spectrum was on the side nearer the sun. Thus, in the halo-curves and the parhelion the red was on the inner circumference, but in the circumzenithal arc the red was on the outer circumference of the curve.

SOLAR HALO OF MAY 20, 1915, AT PHILADELPHIA.

On May 20, 1915, there was a brilliant solar halo visible from about 10 a. m. (75th meridian time) to after noon, at many points in Pennsylvania, Delaware, New Jersey, New York, and Connecticut. This area of visibility corresponded very closely to the area covered by a lunar halo on April 26, 1898, described in this REVIEW, April, 1898, **26**: 168. The phenomenon of the present month caused widespread comment, and quite a little alarm among those ignorant of its true nature and significance; Weather Bureau offices and private observatories were everywhere busy for several hours "answering the questions of the curious and allaying the fears of the superstitious." The nature of many of the questions offers an interesting index of the present unusual mental state of many of our people.

On another page we print Prof. C. S. Hastings's explanation of the halo and interesting features that have been discovered by the aid of photography. George S. Bliss, Section Director in charge of the Weather Bureau station at Philadelphia, sends the following description of the phenomenon as seen at his station:

On May 20, 1915, there was visible at this station, and for some distance around, the most brilliant solar halo I have ever seen. The phenomenon lasted, with little or no change in appearance, from 10 a. m. until 12:30 p. m., when the clouds changed to cirro-cumulus and it disappeared quite abruptly. The inner circle [halo of 22°?] was as bright as any rainbow, while the segment of the outer circle [46°-halo?] was almost as bright, but was limited in extent to an arc of about 60° or 70°. The small secondary circle [parhelic circle] was complete, was very bright, and perfectly white with no yellowish cast.